COMBINING STIMULI SIGNALLING RESPONSE-DEPENDENT FOOD AND SHOCK¹

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Three rats were exposed to a multiple schedule in which separate presentations of light and tone alternated with periods during which light and tone were absent. In Phase 1, light and tone each signalled identical variable-interval schedules of food delivery. In Phase 2, light and tone signalled separate but concurrent variable-interval schedules of food and shock delivery. In both phases, the absence of light and tone was associated with the differential reinforcement of other behavior. Test presentations of light, tone, and a light-plus-tone combination indicated that in both phases, light-plus-tone controlled higher response rates than either light or tone alone. The combination continued to control enhanced responding even when the test stimuli signalled variable-interval schedules of food and fixed-ratio schedules of shock. In these latter sessions, enhanced control by the combination increased shock frequency with no corresponding change in food frequency. Apparently, the level of behavior controlled by the absence of two single stimuli may be more important than the consequences of responding in determining the effects of combined-stimulus presentations.

When behavior that is at a near-zero level in the absence of two single stimuli is increased by response-dependent food delivery in the presence of each of the single stimuli, it increases further when the single stimuli are combined (Meltzer and Freeman, 1971; Miller and Ackley, 1970; Wiltz, Boren, Moerschbaecher, Creed, and Schrot, 1973; Wolf, 1963). On the other hand, when behavior that is at a high level during the absence of two single stimuli is decreased by response-dependent shock delivery during the presence of each of the single stimuli, it decreases further when the single stimuli are combined (Miller, 1969; Reberg and Black, 1969; Van Houten and Rudolph, 1971; Wiltz, 1972).

However, it has recently been found that combined shock-associated stimuli fail to enhance suppression when periods during which both stimuli are absent are deleted from the training schedule (Van Houten and Rudolph,

1971). Furthermore, combined shock-associated stimuli also fail to enhance suppression when the absence of both single stimuli controls low levels of behavior after having previously controlled high levels of behavior (Wiltz, 1972). Finally, combined stimuli signalling only *food delivery* suppress behavior to a greater extent than the single stimuli when the absence of both stimuli controls the highest level of behavior in the training schedule (Howerton, 1972). These studies indicate that the level at which behavior is maintained in the absence of the single stimuli is an important determinant of combined-stimulus control. Thus, an investigation of both appetitive and aversive schedules in the presence of the single stimuli, while maintaining a constant level of behavior in the absence of both stimuli, appears of interest.

The present research compared the control exerted by combined food-associated stimuli and combined shock-associated stimuli when in both cases the absence of the single stimuli controlled a near-zero level of behavior. When it was found that the combined stimuli enhanced behavior in both cases, the research was extended to examine the effects of two different schedules of shock. Initially, a variable-interval shock schedule was used so that enhanced behavior would not increase shock.

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When the combined stimuli continued to enhance behavior, the schedule was changed so that each increment in behavior correspondingly increased shock frequency.

METHOD

Subjects

Three experimentally naive adult male hooded rats, with free-feeding weights between 350 and 450 g, were trained and tested at 80% ($\pm 2\%$) of their free-feeding weight.

Apparatus

Three operant-behavior chambers measuring 203 mm high by 212 mm long by 178 mm wide were used. Each chamber had white translucent plastic side walls, a clear plastic ventilated ceiling, and a floor consisting of 3-mm diameter stainless steel grids spaced 13 mm between centers. A stainless steel lever, requiring a force of about 0.15 N to operate, was positioned on the right side of the front wall, and 45-mg Noyes pellets were delivered to a feeder trough at the left of the lever. Each chamber was enclosed in a sound-attenuating chest and located in a room adjacent to that housing the solid-state scheduling equipment.

The 2000-Hz, 90-dB tone stimulus, measured at the response lever with a Type 1565-A General Radio Sound Level Meter, was presented through a speaker mounted directly above the chamber. The ambient noise level in the chamber, with the exhaust fan running, was about 80 dB. The light stimulus was generated by two 25-W, 125-V bulbs, one horizontally mounted 100 mm from the center of each of the translucent side walls. These bulbs together produced 130.2 cd/m measured with a Honeywell Pentax photometer positioned 125 mm from the side walls of the chamber. In addition, continuous illumination was provided by a 7-W, 120-V bulb, operating at 3 W.

Constant current electric shock was generated by a Lehigh Valley Electronics 1531 shocker scrambler and delivered to the grid floor, front and rear walls, and manipulandum. Terminal shock parameters for each subject were as follows: W-8, 0.15 mA, 0.3 sec; W-13, 0.20 mA, 0.3 sec; W-14, 0.25 mA, 0.4 sec.

Procedure

Preliminary training. For Session 1, each subject was placed in the training chamber

and allowed to make 50 lever presses, each of which produced a single food pellet. For Sessions 2 to 15, each subject was placed on a multiple schedule in which separate periods of light, tone, and neither light nor tone were each associated with identical variable-interval (VI) schedules of food delivery in which the first response occurring an average of t sec after the last food delivery produced food. The value of t was gradually increased from 15 (VI 15-sec) to 60 (VI 60-sec), and the length of the training sessions was gradually increased to 2.5 hr. The duration of light and tone presentations was varied within sessions from 2 to 5 min, and the termination of each of these was followed by a 1.5- to 4-min period with neither light nor tone. The light and tone were each presented about an equal number of times in any session, and the duration of the periods during which both stimuli were absent was shortened to compensate for the larger number of presentations of this component. The sequence of presentations of light and tone was randomized, with the restriction that neither one could be presented more than three times in succession. Food deliveries scheduled but not collected were cancelled with each stimulus change.

Phase 1: food only. When the preliminary training phase was completed, a differential-reinforcement-of-other-behavior (DRO) schedule was substituted for the VI 60-sec schedule during the absence of light and tone. On the DRO schedule, food was presented after a period of time during which no bar presses were emitted. The required time ranged from a minimum of 30 sec to a maximum of 70 sec, and was varied nonsystematically within and between sessions, so that food delivery rates remained equal during all three stimulus conditions. Training was continued until the following criteria were met over five consecutive sessions: (a) an immediate and sustained decrease in responding in at least 80% of the periods with neither light nor tone, (b) immediate and sustained increases in responding in at least 80% of the separate light and tone presentations, and (c) an average response rate when light and tone were absent that was not more than half the average rates during light and tone separately.

After the fifth session that satisfied these criteria, W-8 and W-14 were given a test consisting of 12 randomized 1-min presentations each

of light, tone, and a light-plus-tone combination. The test was preceded by approximately 30 min of warmup on the regular training schedule. One food delivery was scheduled during each test stimulus after an interval of time from the beginning of the stimulus presentation. The interval was the same for each stimulus in any given replication, but varied across the 12 replications. This procedure provided a schedule of food delivery in testing that was similar to that employed in training, while ensuring that food was scheduled with equal frequency and at equal within-stimulus intervals for all three test stimuli. Test stimuli were separated by 1-min periods with neither light nor tone, during which the training DRO schedule remained operative. The test of W-13 differed in that the test stimuli were separated by 20-sec periods with neither light nor tone, and no food was delivered during testing. This animal was tested in extinction to provide a measure of comparison with previous studies using extinction tests (*e.g.*, Wolf, 1963), and to ensure that the test results were not uniquely a function of testing under conditions of maintained food delivery.

Phase 2: food and shock. Each subject was then returned to the training conditions of Phase 1, and a VI 60-sec schedule of response-dependent shock delivery was introduced in addition to the VI 60-sec schedule of response-dependent food delivery during light and tone. The food and shock schedules were always out of phase so that the two events were seldom scheduled simultaneously. As with food, shocks scheduled but not delivered were cancelled with each stimulus change.

Shock intensity and duration were adjusted until, in addition to meeting each of the previously mentioned stimulus-control criteria, responding during light and during tone was reduced to less than 50% of the preshock rate for five consecutive sessions. After the fifth session that satisfied these criteria, each subject was given a second test consisting of 12 randomized 1-min presentations each of light, tone, and light-plus-tone. In order to make the test administered at the end of Phase 2 identical to that administered at the end of Phase 1, no shock was used in the Phase 2 test. This permitted a within-subject comparison of test results under equal conditions of testing after different conditions of training.

Phase 3: maintenance tests. Each subject was returned to the training conditions of Phase 2 for three or four sessions, since response rates had increased substantially during testing without shock. Upon recovery of baseline performance, as determined by an examination of cumulative records, a series of 30 maintenance tests was administered over a period of 30 consecutive sessions. Each test was preceded by a 20-min warmup, and consisted of eight randomized 3-min presentations each of light, tone, and light-plus-tone. The VI 60-sec food schedule was operative during all three test-stimulus conditions in all 30 tests. The VI 60-sec shock schedule was maintained during all three test-stimulus conditions for the first nine tests. In the final 21 tests, the shock schedule was changed to fixed-ratio one (FR 1) to examine the level of responding controlled by the combined stimuli under conditions in which every response produced shock. Test-stimulus presentations were separated by 2-min periods of neither light nor tone, in which the DRO food schedule remained operative.

RESULTS

Training Data

Subjects W-8, W-13, and W-14 required 28, 38, and 24 sessions, respectively, to complete Phase 1. An additional 19, 15, and 16 sessions, respectively, were required for Phase 2. The response rates of individual subjects in the five criterion sessions, which are presented in Table 1, indicate that (a) in the final five sessions of both phases, response rates when the light and tone were absent were less than 20% of the rates during light or tone alone for all subjects, and (b) in the final five sessions of Phase 2 (food and shock), response rates during light and during tone were less than 50% of the rates during these stimuli in the final five sessions of Phase 1 (food only). The mean frequencies of food delivery for individual subjects in each stimulus condition in each phase are also shown in Table 1. The similarity of these frequencies, which are representative of the frequencies in the final five criterion sessions and in most other training sessions, indicate that the results may not be attributed to differential frequencies of food delivery in the presence of the different stimuli either within or between phases.

Table 1
Training Data for Individual Subjects

Subject	Phase	Responses per Minute			Pellets per Minute		
		Light	Tone	Light Out-No Tone	Light	Tone	Light Out-No Tone
W-8	1	50.1	47.3	5.4	0.98	1.00	0.98
	2	10.5	10.3	0.6	0.97	0.97	0.98
W-13	1	19.4	19.3	3.6	0.92	0.93	0.92
	2	5.9	6.2	0.9	0.90	0.90	0.92
W-14	1	21.7	20.6	2.7	0.91	0.91	0.92
	2	8.7	6.9	0.5	0.90	0.90	0.92

Note: Response rates represent means of the final five training sessions for each subject in each phase. Food delivery rates represent averages of all training sessions for each subject in each phase.

Cumulative records showed that immediate and sustained increases in responding occurred in more than 80% of the presentations of light and tone, and immediate and sustained decreases in responding occurred in more than 80% of the periods with neither light nor tone.

Test Results

Tests 1 and 2. Table 2 shows the number of responses emitted by individual subjects in

the four stimulus conditions in consecutive quarters of each of the first two tests. Each quarter consists of three consecutive replications of stimulus presentations. In Test 1, which examined the effects of combining stimuli signalling only food, each subject emitted more responses during light-plus-tone than during either light or tone alone. This finding is particularly clear in the case of W-13, but is also evident in the test results of the

Table 2
Test Responses for Individual Subjects

Subject	Replication	Test 1				Test 2			
		Light Out-No Tone	Light	Tone	Light Plus Tone	Light Out-No Tone	Light	Tone	Light Plus Tone
W-8	1-3	21.3	207	174	238	2.3	39	52	46
	4-6	26.3	220	175	249	6.3	70	105	91
	7-9	17.3	167	150	214	12.0	102	75	144
	10-12	23.0	211	180	198	28.7	138	130	150
	Total	87.9	805	679	899	49.3	349	362	431
W-13	1-3	32.0	43	12	74	2.0	23	18	46
	4-6	30.0	32	27	72	5.0	38	12	75
	7-9	11.0	28	22	40	17.0	24	3	50
	10-12	19.0	34	27	68	9.0	57	17	63
	Total	92.0	137	88	254	33.0	142	50	234
W-14	1-3	2.0	95	51	107	1.0	16	4	18
	4-6	3.0	44	54	104	0.0	27	26	38
	7-9	5.3	77	58	94	1.0	14	10	25
	10-12	3.0	63	53	77	1.3	27	10	16
	Total	13.3	279	216	382	3.3	84	50	97

Note: Since total light-out-no-tone exposure for W-8 and W-14 amounted to three times that of each separate test stimulus, these data points have been divided by three to facilitate comparison with test stimuli.

other two subjects. The effect was consistently observed across all four test quarters for W-13 and W-14, and all but the final test quarter for W-8.

In Test 2, which examined the effects of combining stimuli separately signalling both food and shock, each subject again emitted more responses during light-plus-tone than during either light or tone alone. Again, this finding was particularly clear in the case of W-13, but was also observed in the test results of the other two subjects. The effect was consistently observed in all four test quarters for W-13, in all but the final test quarter for W-14, and in the last two test quarters for W-8.

Subjects W-8 and W-14 emitted substantially fewer test responses during Test 2 than during Test 1. Therefore, a detailed comparison of the results of Tests 1 and 2 cannot be made on the basis of the absolute number of test responses emitted during each test stimulus. However, by presenting each data point as a percentage of the total responses emitted during all three test stimuli, Figure 1 provides a comparison of the distribution of responses across test conditions in each of the first two tests. Figure 1 indicates that there was no appreciable difference between the proportion of responses emitted during combined food-associated stimuli in Test 1 and combined food-and-shock-associated stimuli in Test 2.

Maintenance Tests. Figure 2 shows, for each stimulus condition, the mean number of responses per test for successive blocks of three tests in Maintenance Tests 1 to 30. The data indicate that the light-plus-tone combination continued to control a greater number of responses than either light or tone alone for all subjects in the large majority of maintenance tests. This finding is not due to averaging blocks of three tests, since examination of individual test data indicated that enhanced combined-stimulus control was observed in 82 of the 90 maintenance tests. Calculation of mean response percentages for individual subjects over Maintenance Tests 1 to 9, during which VI 60-sec food and shock schedules were operative, revealed that light-plus-tone controlled 38.3, 42.9, and 39.5% of the responses emitted during the three test stimuli for W-8, W-13, and W-14, respectively. Similar calculations over Maintenance Tests 10 to 30, during which VI 60-sec food and FR-1

Fig. 1. Cumulative percentage of responses emitted during light, tone, and light-plus-tone by each subject in consecutive quarters of Tests 1 and 2. Each test was completed in a single session, and each test quarter consisted of three replications of 1-min presentations of each of the test stimuli. Points were calculated by summing the number of responses accumulated in the stimulus under consideration, and dividing the total by the sum of responses accumulated in all test stimuli.

Fig. 2. Maintenance Test results for individual subjects. The mean number of responses per test during each stimulus condition is shown for successive blocks of three consecutive tests. Points to the left of the break within each panel describe results for the first nine Maintenance Tests, while those to the right show results for the final 21 Maintenance Tests. Since the time during which light and tone were absent equalled twice the length of time of the other stimulus conditions, response means during the absence of light and tone have been divided by two to facilitate comparison with test stimuli.

shock schedules were in effect, showed that light-plus-tone controlled response percentages of 36.8, 39.3, and 40.2 for the same subjects.

Throughout the first nine maintenance tests, both food and shock rates were essentially equal across all three test stimuli. For all subjects combined, the mean rate of food delivery during the combined stimuli was 0.86 pellets per minute, while the mean rate during the single stimuli was 0.87 pellets per minute. The mean rate of shock delivery during the com-

bined stimuli was 0.74 shocks per minute, while the mean rate during the single stimuli was 0.73 shocks per minute. Thus, the combined stimuli continued to control enhanced responding in these tests, even though higher response rates did not change either the rate of food delivery or the rate of shock delivery. Throughout the final 21 tests, the rate of food delivery continued to be about equal in all three test stimuli, while the shock rate was consistently higher during the combined stim-

uli. The overall mean rate of food delivery during the combined stimuli was 0.75 pellets per minute, while the mean rate during the single stimuli was 0.73 pellets per minute. On the other hand, the mean rate of shock delivery during the combined stimuli was 3.44 shocks per minute, while the mean rate during the single stimuli was only 2.69 shocks per minute. Thus, the combined stimuli continued to control enhanced responding in these tests, even though higher response rates resulted in a higher shock rate during the combined stimuli without a corresponding increase in the rate of food delivery.

DISCUSSION

The results of the initial comparison tests indicated that combined stimuli separately signalling both food and shock, as well as combined stimuli separately signalling only food, controlled higher response rates than the single stimuli. The proportion of responses emitted during combined shock-associated stimuli did not differ from the proportion of responses emitted during combined stimuli signalling only food. Furthermore, the results of maintenance testing showed that combined shock-associated stimuli continued to control enhanced responding for extended periods of time, even when enhanced responding increased shock frequency. This seemingly paradoxical effect cannot be attributed to ineffective shock parameters, since the shock clearly reduced response rates below the pre-shock baseline.

The major difference between the present study and previous experiments was the level of responding maintained in the absence of the shock-associated stimuli. In the present study, the absence of the shock-associated stimuli controlled a near-zero response rate; in previous studies the absence of the shock-associated stimuli controlled a high response rate. Thus, the level of behavior controlled by the absence of the single stimuli may be more important than the consequences of responding in determining combined-stimulus control.

A number of other studies have described conditions under which suppressive effects of response-dependent electric shock are overpowered. For example, after alternating sessions of extinction with sessions in which responses produced both food and shock, Holz

and Azrin (1961) found that introduction of shock in the extinction sessions resulted in an immediate and sustained increase in responding. They suggested that the procedure of selectively pairing food and shock had resulted in shock acquiring discriminative control over responding, and that "... the discriminative property came to exert an even greater effect on responding than did the aversive property (p. 231)." As another example, Kelleher and Morse (1968) obtained positively accelerated patterns of responding when the only scheduled consequence of responding was an electric shock delivered on a fixed-interval schedule. When shock on an FR schedule alternated with shock on the FI schedule in another portion of the study, responding was suppressed during the FR component but remained enhanced during the FI component. Since the FR response patterns resembled those typically obtained with shock, while the FI response patterns resembled those typically obtained with food, Kelleher and Morse concluded that "... the schedule of reinforcement can be more important than the nature of the reinforcer (p. 836)."

In each of these experiments, enhanced responding increased shock frequency, and in each case the results were attributed to the overriding influence of scheduling variables. The present results may be viewed in a similar manner if it is considered that, in determining combined-stimulus control, the effects of the *schedule* maintaining behavior in the absence of the single stimuli may be more powerful than the suppressive effects of shock. Thus, the results do not necessarily demonstrate the functional identity of shock and food in influencing combined-stimulus control. Indeed, shock parameters other than those used in the present study may overcome scheduling effects and alter the nature of combined-stimulus control. At least within the confines of the present experiment, however, the results may demonstrate that the level of behavior maintained in the absence of the single stimuli, rather than the consequences of responding, is of primary importance in determining combined-stimulus control.

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